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Confinement of sows 24 hours before expected farrowing affects the performance of nest building behaviours but not progress of parturition

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Abstract

The effects of confinement prior to farrowing on the performance of nest building behaviour and progress of parturition were investigated using hyper prolific sows. Forty first parity and 40 second/third parity sows were allocated to one of two treatments: loose housed or confined. All sows were housed in a freedom farrowing pen with an option of confinement and free access to a straw rack with long stemmed straw. Loose sows were loose housed throughout the observational period and confined sows were confined from 2 days before expected farrowing until the completion of parturition. Sows were video recorded from 2 days before expected farrowing until birth of the last piglet, and behaviours (biting/rooting pen fittings, straw directed and rooting/pawing floor) and postures (lying sternal, lying lateral, sitting and standing/walking) of the sows during the last 24 hours before farrowing were registered continuously. The time of birth of every piglet was registered from the video recordings, and it was noted if the piglet was alive or stillborn. Treatments were compared by use of linear models with treatment and parity as fixed effects. Results showed that confinement did not influence duration of the nest building period, but affected the performance of nest building behaviour. Loose housed sows tended to perform more nest building behaviour during the nest building period than confined sows (817 (95% CI: 713-929) vs 686 (95% CI: 590-789) s/h/sow, P=0.08). Loose housed sows had fewer bouts of nest building behaviours than confined sows (4.6±0.48 vs 6.1±0.48 bouts/sow/h, P=0.03) but mean duration of bouts was longer (154 (95% CI: 136-173) vs 98 (95% CI: 83-114) s/bout, P<0.001). Loose housed sows tended to spend a greater proportion of time during the nest building period standing/walking (21±1.33 vs 17±1.33 min/h, P=0.05). No differences were found in total born per litter (L: 17.4±0.4; C: 17.6±0.4, P=0.70), the duration of farrowing (L: 283 min (95% CI: 244-324); C: 258 min (95% CI: 222-297), P=0.38), mean birth interval (L: 17.4 min (95% CI: 15.1-19.9); C:15.7 min (95% CI: 13.518.0), P=0.30), or number of stillborn (L: 0.5 (95% CI: 0.3-0.8); C: 0.7 (95% CI:0.5-1.1), P=0.18). In

conclusion, loose sows spent a greater proportion of the nest building period performing nest building, especially rooting and pawing behaviors, in comparison with confined sows. Furthermore, loose housed sows were standing or walking more than confined sows, but housing did not affect duration of farrowing or piglet birth intervals.

Keywords: Confinement, Farrowing duration, Free farrowing, Nest building behaviour, Sows, Stillborn piglets

1. Introduction

Nest building in sows can be considered as a behavioural need, since it is induced by hormonal changes that occur close to farrowing regardless of the environment (Algers and Uvnas-Moberg, 2007). Restricting the sows' ability to perform nest building behaviour has been linked to elevated stress levels of the pre-farrowing sows (Lawrence et al., 1994; Jarvis et al., 1997), increased farrowing duration and an increased number of stillborn piglets (Thodberg et al., 1999; Thodberg et al., 2002; Oliviero et al., 2008).

Although internally induced, the expression of nest building behaviour can be modulated by external influences. Availability of nest building material increased the expression of nest building behaviours, with increased durations of pawing and rooting, and decreased stereotypic behaviours. Furthermore, provision of nest building material reduced the proportion of time spend sitting and standing during the nest building phase (Cronin et al., 1994; Thodberg et al., 1999). In addition, research has shown that the expression of nest building behaviour is affected by housing conditions, with sows in crates showing increased durations of sitting and lying, and changing postures more often, during the nest building phase compared to loose housed sows (Cronin et al., 1994; Lawrence et al., 1994; Damm et al., 2003b). Confinement in crates also decreased the proportion of time the sows spend rooting and pawing, and they showed an

increase in expression of stereotypic behaviours compared to loose housed sows (Cronin et al., 1994; Lawrence et al., 1994; Damm et al., 2003b). In addition, parity or previous housing experience can affect prepartum nest building, as some adaption to farrowing in crates seems to occur (Thodberg et al., 1999; Jarvis et al., 2001).

From previous studies it is, however, difficult to determine which is more important to the pre-farrowing sow: being able to move around freely or having access to nest building material? In some studies investigating nest building behaviours and/or farrowing progress of confined and loose housed sows, nest building material was only available for sows in pens (Cronin et al., 1994; Lawrence et al., 1994; Jarvis et al., 2000; Oliviero et al., 2008). In other studies, the amounts or kind of nest building material differed between the confined and loose housed sows (Damm et al., 2003a; Chaloupkova et al., 2011). It is important to determine whether the provision of nest building substrate to confined sows allows adequate expression of nest building for sow welfare, since confinement of sows at the time of farrowing is still considered necessary to safeguard piglet welfare by the majority of commercial pig producers (Hales et al., 2015b).

Consequently, the objective of this study was to investigate the difference in performance of nest building behaviours in confined and loose housed sows, when they were provided with equal amounts of straw to use as nest building material. We hypothesised that the sows would perform more nest building behaviours if housed loose compared to when crated.

2. Material and methods

This experiment was conducted in accordance with the guidelines of the Danish Ministry of Justice Act No. 382 (June 10, 1987) and Acts 333 (May 19, 1990), 726 (September 9, 1993) and 1016 (December 12, 2001) with respect to animal experimentation and care of animals under study.

93 *2.1. Experimental design and Housing*

94 During mating and gestation the sows were loose housed in stable groups of 50 to 60
95 animals. The animals were in the mating unit with free access stalls for one week, after which
96 they were transferred to the gestation unit with electronic sow feeders. Four to seven days before
97 expected parturition the sows were moved to the farrowing unit where they were placed in
98 individual SWAP farrowing pens, as previously described by Hales et al. (2015b).

99 In the current experiment 40 first parity sows and 41 second/third parity sows were
100 allocated to one of two treatments: loose housed (40) or confined (41). First parity sows were
101 randomly allocated to either the confined or the loose treatment, whereas second parity sows
102 returned to the same treatment they were allocated to as parity one animals and third parity
103 sows returned to the same treatment they received in parity two. Confined sows were loose
104 housed at entry into the farrowing pen and then confined from day 114 of gestation (2 days
105 before expected farrowing) until day 4 after farrowing, whereas loose sows were loose housed
106 throughout the experimental period.

107 During the experimental period sows were individually housed in SWAP pens which is a
108 commercially available farrowing pen designed for loose sows with an option of confinement.
109 A detailed description of the pen has been provided by Hales et al. (2015b). In brief, the SWAP
110 pen measured 3.0 x 2.1 m, with 60% solid concrete floor and 40% cast iron slats in the area of
111 the pen furthest from the inspection aisle. A covered piglet creep area of approximately 1 m^2
112 was placed in one corner of the pen closest to the aisle. The creep area had solid flooring with
113 a floor heating system, which was turned on from the time of sow placement in the farrowing
114 unit. The front of the creep formed a swing-side that hinged on the front wall of the pen to form
115 a crate for the sow against one side wall, where a sloping wall provided support for the sow
116 when lying down from standing and protection for piglets against crushing. A straw rack was

placed on the gate to the inspection aisle, above the feeding trough used when the animals were confined.

2.2. Animals and management

The sows (Danish Landrace x Danish Yorkshire) were mated with semen from Duroc boars (Hatting KS, Horsens, Denmark) and fed according to Danish recommendations (Tybirk et al., 2014). From placement in the farrowing unit, the sows were fed a commercially formulated lactation diet three times per day (0730, 1230, and 1500 hours). The diet was in mash form with barley, wheat and soybean meal as the main ingredients, contained 8.7 MJ potential physiological energy (Boisen, 2001) and 7.5 g standardized ileal digestible lysine/kg feed. Before farrowing, the sows received 3.7 kg feed/day; this was reduced to 2.7 kg/day at two days before expected parturition (day 114 of gestation), at the same time as sows selected for the confinement treatment were crated. Water was available at all times from a drinking nipple in the feeding trough. All sows had free access to long-stemmed barley straw from the straw rack. The straw rack was filled once daily (1230) and contained approximately 1 kg of straw when full.

Staffs was generally present from 0700 to 1600 hours every day and the sows were managed according to the general routines of the herd. The lights in the farrowing unit were on for 24 hours a day to allow video recordings, from two days before the first sows were expected to farrow until 4 days after the last sow had farrowed.

2.3. Video recordings

Video cameras (PTZ security IR-Dome model no. 795JH, PTZ Security, Esbjerg, Denmark) were placed above the pens with one camera covering 1 or 2 pens depending on the placement of the camera. The sows were video recorded from two days before expected farrowing until four days after farrowing. Video recordings were made using Axxon Next software (AxxonSoft, Moscow, Russia), stored in avi format and then converted into jpg files

using OGG converter version 5.7 (HOO Technologies, Santa Barbara, USA). The jpg files could then be read in a software programme developed by the Danish Pig Research Centre for performing behavioural observations and registrations (RADRA version 2.3, Danish Pig Research Centre, Copenhagen, Denmark).

2.4. Behavioural observations

Continuous observation of the video recordings started 24 hours before the birth of the first piglet and ended after the birth of the last piglet. An observer recorded the exact date and time of expulsion of each piglet in the litter, as well as whether the piglet was stillborn (no visible movement) or live born. The ethogram shown in Table 1 was used for registration of behaviours. Sow posture was recorded every time the sow changed position from one posture to another and it was noted when any of the specific behaviours started and ended. Active was defined as 'biting/rooting pen fixtures'. 'rooting/pawing the floor, straw directed behaviour and eating/drinking.

The start of the nest building period was defined as the first hour in which at least 8 minutes of nest building behaviours (rooting/pawing floor, rooting/biting pen fixtures and straw directed behaviour) occurred. The end of the nest building period was defined as the last hour with at least 8 minutes of nest building behaviours before birth of the first piglet, or the hour where the first piglet was born. Both the first and last hour with performance of nest building behaviours were included in the nest building period.

2.5. Salivary cortisol

Saliva samples were collected daily at 0800, 1300, and 1600, from two days before expected parturition, using a Salivette ® (Sarstedt, Nürnbrect, Germany) by fastening the cotton roll to a clamp and letting the sow chew on the cotton roll until it was saturated. The clamp was attached to a long stick to avoid entering the pen if the sow was out of reach from the aisle. The saturated cotton roll was returned to the Salivette container and centrifuged for

2 minutes at 1,000 g within one hour of sampling to extract saliva, that was then stored at -2 °C. After the last sampling at 1600 hours, a pooled sample for each day was made of 100 μL of saliva from each sampling time in an eppendorf tube that was stored at -20 °C. Concentrations of salivary cortisol were determined by assaying duplicate samples using a commercial salivary cortisol enzyme immunoassay kit (Salimetrics Europe, Sudbury, United Kingdom). Using SigmaPlot ver. 12.5 (Systat Software Inc., San Jose, CA, USA) a 4-parametric non-linear regression curve was fitted to the abundance readings of the standard curve and the concentrations of saliva cortisol were subsequently determined in nmol/L.

2.6. Calculations and statistical analysis

All statistical analyses were performed using SAS ver. 9.3 (SAS Institute Inc., Cary, NC, USA) with each sow as the experimental unit. Farrowing duration was calculated as time from birth of first piglet to birth of last piglet. Birth interval was calculated as the time between two successive piglets. Data were analysed univariately in normal linear models using the MIXED procedure:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$$

where Y_{ijk} is the observed response, μ is the overall mean, α_i is the effect of housing, β_j is the effect of parity, $(\alpha\beta)_{ij}$ the interaction between housing and parity, and ε_{ijk} is the residual error. If the interaction between housing and parity was non-significant ($P > 0.05$), it was excluded from the model.

Data on stillborn piglets were discrete and were analysed using the same generalized linear model with an underlying Poisson distribution, using the GENMOD procedure which is a transformation of data to a linear regression with a logarithmic function. To ensure homogeneity of variance for activity, nest building behaviours, duration performing behaviour, farrowing duration and birth interval a square root transformation of the variable was

191 performed. Salivary cortisol concentrations were logarithmically transformed and analysed
192 univariately using the MIXED procedure:
193 $Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + \delta x_{ij} + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijk}$
194 where Y_{ijk} is the observed response, μ is the overall mean, α_i is the effect of housing, β_j is the
195 effect of parity, γ_k is the effect of day, δx_{ij} is a regression on salivary cortisol concentrations at
196 day -2, $(\alpha\beta)_{ij}$ is the interaction between housing and parity, $(\alpha\gamma)_{ik}$ is the interaction between
197 housing and day, $(\beta\gamma)_{jk}$ is the interaction between parity and day, $(\alpha\beta\gamma)_{ijk}$ is the interaction
198 between housing, parity and day, and ε_{ijk} is the residual error. If the interactions were non-
199 significant ($P > 0.05$), they were excluded from the model.
200 Estimated least-squares means and standard errors are presented for the normally
201 distributed data. For the square root and logarithmically transformed data, the back-transformed
202 data and 95% confidence intervals are presented. The estimation method was based on residual
203 maximum likelihood (REML). Statistical significance was accepted at $P \leq 0.05$ and $P \leq 0.10$
204 was considered a tendency.
205
206 **3. Results**
207 Of the 81 sows selected for this study, one first parity sow in the confined treatment did
208 not meet the criteria of having at least 8 minutes/hour with performance of nest building
209 behaviours, and was subsequently excluded from the analysis of the behaviours in the nest
210 building period. For all the analysed variables, the interaction between housing and parity was
211 non-significant. Time performing behaviours is expressed both as s/h for the 24 h pre
212 farrowing (Table 2) and for the nest building period (Table 4, 5). Pairs of numerical results
213 are always presented for confined then loose sows, and for first parity the parity 2/3 sows,
214 corresponding to the layout in Tables 2-5.

During the 24 hours before birth of the first piglet, loose housed sows were more active (446 vs 607 s/h, P = 0.002) and showed more nest building behaviour (354 vs 515 s/h, P = 0.001), especially rooting and pawing the floor (213 vs 379 s/h, P < 0.001), than confined sows (Table 2). For the 24h period before birth of the first piglet, parity 2 and 3 sows showed fewer posture changes (367 vs 267, P < 0.001), but were more active (471 vs 578 s/h, P = 0.031) and tended to show more nest building behaviours (387 vs 477 s/h, P = 0.064), compared with first parity sows (Table 2).

All sows started nest building around 16 to 17 hours before onset of farrowing, but loose housed sows ended nest building closer to parturition than confined sows (300 min vs 212 min, P = 0.042, Table 3). However, duration of the nest building period was not affected by housing (P = 0.179). Sows of second or third parity ended their nest building period later than first parity sows (321 min vs 191 min before farrowing, P = 0.032) and parity consequently tended to influence the duration of the nest building period (P = 0.066).

Neither housing nor parity affected the average number of posture changes during the nest building period (Table 4). Confined sows showed a tendency for more bouts of lying sternally (P = 0.055) and time per hour spent in sternal recumbency (P = 0.085) over the nest building period compared with loose sows. Confined sows were observed lying laterally for longer bouts than loose housed sows (354 vs 195 s, P < 0.001), while the bouts of sitting (40 vs 56 s, P = 0.007) and standing/walking (185 vs 234 s, P = 0.030) were longer for loose housed sows than for the confined sows. Loose housed sows tended (P = 0.053) to spend more time per hour standing or walking than confined sows.

First parity sows had more bouts per hour of lying sternally (7.4 vs 5.2, P < 0.001) but the bouts were shorter (114 vs 207 s, P < 0.001) compared with sows of parity 2 and 3. First parity sows also had more bouts lying laterally (3.9 vs 1.8, P < 0.001) that were of shorter duration (206 vs 340 s, P = 0.004), such that first parity sows spend more time lying laterally

per hour (1167 vs 870 s/h, P = 0.024) than second/third parity sows during the nest building period. Second/third parity sows were sitting (40 vs 56 s, P < 0.001) and standing/walking (168 vs 254 s, P < 0.001) for longer bouts, and during the nest building period they were standing/walking for a longer time per hour (1112 vs 1200 s/h, P = 0.044) in comparison with first parity sows.

The results of the specific nest building behaviours are shown in Table 5. Confined sows had a greater number of bouts per hour performing nest building behaviour (6.1 vs 4.6, P = 0.030) but the bouts were shorter (98 vs 154 s, P < 0.001), so that overall duration of nest building behaviour per hour tended to be shorter (P = 0.079) compared with loose housed sows. These differences in overall nest building behaviours between confined and loose housed sows were caused by confined sows showing more bouts of biting or rooting pen fixtures (1.6 vs 0.9, P = 0.001) that tended to be shorter (89 vs 111 s, P = 0.058), but the overall duration tended (P = 0.057) to be greater. Loose housed sows had longer bouts (92 vs 167 s, P < 0.001) of rooting or pawing the floor and rooted or pawed the floor for longer overall (393 vs 603 s/h, P < 0.001).

Second and third parity sows had longer bouts of nest building behaviour (92 vs 161 s, P < 0.001) as the bouts of biting or rooting pen fixtures (82 vs 120 s, P < 0.001), rooting or pawing floor (95 vs 163 s, P < 0.001) and showing straw directed behaviour (144 vs 123 s, P < 0.001) were longer compared with first parity sows.

Salivary cortisol concentrations during the nest building period are shown in Figure 1. Overall, salivary cortisol concentrations were lower in confined compared with loose housed sows (13 vs 20 nmol/L, P < 0.001). On the day of parturition salivary cortisol concentration was greater among sow of parity two and three than among first parity sows.

Housing of the sows did not influence farrowing duration (P = 0.377) nor birth intervals (P = 0.299, Table 6). However, second and third parity sows had longer farrowing duration

(220 vs 326 min, $P < 0.001$) and birth intervals (15 vs.18 min, $P = 0.041$) than first parity sows. Second and third parity sows, furthermore, gave birth to more total born (16.0 vs 19.0 piglets/litter, $P < 0.001$), live born (15.4 vs 18.0 piglets/litter, $P < 0.001$) and stillborn (0.5 vs 1.0 piglets/litter, $P = 0.009$) piglets.

4. Discussion

During the 24 hours before farrowing loose housed sows were more active than confined sows because they spent more time nest building, which is in accordance with previous findings that nest building is more elaborate among sows housed in pens compared with confinement in crates (Thodberg et al., 2002; Damm et al., 2003a). It was expected that confined sows would perform more posture changes as previously reported (Jarvis et al., 2001; Thodberg et al., 2002; Damm et al., 2003a), however in the current study the number of posture changes was not affected by housing.

Regardless of housing, second and third parity sows changed posture less often than first parity sows in the current study. Jarvis et al. (2001) reported a tendency to a reduction in posture changes from first to second parity in confined sows, but not in loose housed sows, while Thodberg et al. (2002) observed no difference in the number of position changes between first and second parity sows.

In the present study sows started nest building around 16 hours before birth of the first piglet regardless of housing and parity. In agreement, Damm et al. (2003a) stated that housing did not influence when sows started nest building, but in their experiment the sows started nest building closer to parturition (11 ± 2.7 hours). In contrast, Thodberg et al. (2002) reported that sows confined in crates started nest building later than sows housed in "Get Away Pens" (GAP); approximately 30 h vs. 38.5 h before parturition. However, differences in definitions of the start and end of the nest building period between studies might explain some of the observed

290 variation. On the other hand, The cessation of nest building has been suggested to be strongly
291 correlated with the dramatic rise in oxytocin levels 4h prior to parturition (Castren et al., 1993),
292 penned (loose) sows showed higher levels of oxytocin than crated ones (Oliviero et al., 2008).
293 In the current study loose housed sows stopped nest building closer to parturition than
294 confined sows, in contrast to reports by Thodberg et al. (2002) and Damm et al. (2003a). In
295 agreement with the present findings, Thodberg et al. (2002) observed that older sows stopped
296 nest building closer to birth of the first piglets compared with parity 1 sows. No parity effect
297 regarding termination of nest building behaviour was however reported by Damm et al. (2003a).
298 Previous studies have shown that housing had no effect of the duration of nest building period
299 (Thodberg et al., 2002a; Damm et al., 2003a), even though Damm et al. (2003a) reported a
300 tendency for the nest building period to be longer in confined sows. In these other studies,
301 inadequate ability to express nest building behaviour meant that it continued for longer (even
302 after farrowing) so our findings do not suggest that confined sows had thwarted behaviour since
303 they stopped nest building earlier than loose sows.
304 During the nest building period, loose sows spent more time standing/walking (longer
305 bouts) as opposed to the findings by Lawrence et al. (1994) and Damm et al. (2003a). The
306 longer bouts of standing/walking among the loose housed sows in the current study were related
307 to the increased performance of nest building behaviours, especially rooting or pawing the floor.
308 Loose housed sows were performing rooting or pawing behaviours in half the time they were
309 observed standing or walking, while the confined sows were only performing these behaviours
310 in one third of the time.
311 Surprisingly, loose sows also had longer bouts of sitting, which is often viewed as an
312 abnormal behaviour caused by crating (Jarvis et al., 2001). Previous studies have found that
313 sows confined in crates had higher frequencies of sitting (Cronin et al., 1994; Jarvis et al., 2001;
314 Damm et al., 2003a) and lying (Cronin et al., 1994; Lawrence et al., 1994) than loose housed

315 sows. Furthermore the loose sows in the current study spent a little less time in sternal lying,
316 which might reflect constraints of the crate for confined sows in accordance with the findings
317 of Lawrence et al. (1994). Damm et al. (2002) found a tendency for crated first parity sows to
318 spend more time in sternal recumbency, and speculated that they were more uncomfortable than
319 loose housed sows, due to the confined environment. However, other authors have simply
320 reported that confined sows in general lie down more than loose housed sows (Cronin et al.,
321 1994; Damm et al., 2003a). As there were no overall differences in posture changes in the
322 current study between confined and loose sows this might suggest no effect of housing on
323 general restlessness of the sows.

324 As expected, the overall performance of nest building behaviours was increased in the
325 loose housed sows compared to the confined sows, which has previously been found by several
326 other authors (Cronin et al., 1994; Lawrence et al., 1994; Thodberg et al., 2002; Damm et al.,
327 2003a). This was also apparent, when looking at the behaviours separately, except for the
328 performance of straw directed behaviour. The amount of straw directed behaviour did not differ
329 and the sows only used approximately 1 min/h during the nest building period performing this
330 behaviour. However, the registrations of straw directed behaviour only included behaviours
331 directed at the straw rack, because it was not possible from the video recordings to distinguish
332 between rooting the floor and rooting straw on the floor. The recording method may therefore
333 have influenced the results, and it is also possible that providing straw in a straw rack was not
334 adequate to fulfil the sows' motivational need to manipulate nest building material. Damm et
335 al. (2005) have previously shown that sows would not use straw or hay as nest building material
336 if provided in a straw rack, but they would use large amounts of straw for nest building when
337 provided on the floor. The current study therefore shows that when sows are provided with
338 access to straw from a straw rack, housing did not affect the amount of time the sows spent
339 taking straw from the rack and sows only spent a small fraction of the time during nest building

on straw directed behaviours. In consequence, straw did not accumulate on the ground and this may have masked possible differences in the behavioural repertoire of the sows.

Rooting or pawing the floor were performed more by the loose housed sows than by the confined sows during the nest building period, which is in agreement with findings by Lawrence et al. (1994), Thodberg et al. (2002) and Damm et al. (2003a). Cronin et al. (1994) found that pawing was performed more often by sows in crates than in pens, but that rooting was performed more often by sows in pens. In the current study it was not possible to distinguish between rooting and pawing on the video recordings and consequently these observations had to be pooled. It has been reported from observations of free-range sows, that rooting and pawing behaviours often occur simultaneously during nest building (Jensen et al., 1993) making it legitimate to pool these observations.

Loose housed sows had longer bouts of rooting or pawing the floor than confined sows, which could support that the expression of nest building behaviours is more fragmented in confined sows. It has been suggested that, in confined sows, nest building behaviours are decreased because the sows do not have enough space in the crate for their satisfactory performance (Jarvis et al., 2002; Damm et al., 2003a).

Walking activity is a part of the natural nest preparation behaviour in sows, and free-range domestic sows have been reported to walk several kilometres during the last 24 hours pre-farrowing in search for a nest site (Jensen, 1986). Furthermore, Haskell and Hutson (1994) showed that sows housed in a test arena (6.5 x 7 m) walked a longer distance the last day before parturition, compared to the 3 previous days. Walking therefore seems to be an important part of the nest building behaviour in sows, and depriving the sows of the ability to perform this activity by confinement during nest building may therefore be the main reason why differences in behavioural expression were found between the confined and loose housed sows.

364 Biting or rooting pen fixtures was performed more by the confined sows than by the loose
365 housed sows, which is in accordance with previous findings (Cronin et al., 1994; Lawrence et
366 al., 1994; Jarvis et al., 2001; Damm et al., 2003a). Although biting or rooting pen fixtures are
367 often defined as stereotypic behaviours, it is not likely this was the case here, as these types of
368 behaviours are developed over time (Lawrence and Terlouw, 1993). The sows in the current
369 study were only confined for two days before expected farrowing and their performance of
370 biting/rooting pen fixtures might have been an expression of frustration due to their inability to
371 turn/walk.
372 In the present study housing did not affect farrowing duration or birth interval. Previously,
373 Oliviero et al. (2008) have reported longer farrowing duration for sows housed in crates
374 compared to sows housed in pens (311 ± 35 min vs. 218 ± 24 min, P = 0.03). However, those
375 sows had much smaller litter sizes than in the current study (liveborn: 11.4 ± 2.4, stillborn: 1.1
376 ± 1.1), and the treatment groups differed not only in confinement but also in availability of nest
377 building material. In the study of Hales et al. (2015a), both confined and loose housed sows had
378 access to straw as nest building material, and no differences in the duration of farrowing was
379 seen.
380 Salivary cortisol, measured as an indication of physiological stress, was surprisingly
381 higher in loose sows in the present study which is in contrast to previous work (Oliviero et al.,
382 2008). The higher cortisol levels might be a reflection of greater activity or arousal in the loose
383 sows. There was no evidence for changes in farrowing which might indicate activation of
384 adrenal and sympathetic stress physiology systems and previous studies have also been
385 inconsistent about these effects of confinement. All sows in the present study were loose housed
386 in gestation so they might have been in a better general condition or had a healthier muscle tone
387 than sows confined in gestation, as used in many earlier studies.

Some previous studies have linked loose housing of farrowing gilts with a lower proportion of stillborn piglets (Thodberg et al., 2002; Pedersen and Jensen, 2008). However, more recent and larger studies have failed to replicate such results (Oliviero et al., 2008; Hales et al., 2015a; Hales et al., 2015b). In the present study second/third parity sows had more total born piglets than any of the other groups; as it has previously been shown that the risk for stillborn piglets increases with increasing litter size (Herpin et al., 1996; Thodberg et al., 2002), this result was to be expected

5. Conclusion

Loose housed sows spent a greater proportion of the nest building period performing nest building behaviours, especially rooting and pawing the floor, in comparison with confined sows. In addition, loose housed sows were standing or walking more than confined sows. Housing did not affect duration of farrowing or birth intervals. The current study provides some evidence that crating modified nestbuilding behaviour, but to a rather limited extent under the conditions of this experiment with no evidence of significant adverse consequences for the sow when measured as restlessness, salivary cortisol, stereotypy development or prolongation of farrowing.

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500 **Table 1**

501 Ethogram of behaviours recorded in sows before and during farrowing.

Behaviour	Description
Postures:	
Lying sternally	Lying on the belly, with the front legs under the sow
Lying laterally	Lying on the side with the udder exposed
Sitting	Sitting with front legs straight and both front hooves on the ground.
Standing/walking	Standing up and/or walking around in the pen or moving backwards-forwards in the crate
Nest building:	
Biting/Rooting pen fixtures	Biting or rooting behaviors directed at the pen, escape attempts from confinement or trying to jump out of pens
Rooting/pawing floor	Moving the snout in forward-backwards motions on the floor and/or pawing the floor with either front leg
Straw directed behavior	Any behavior directed at the straw rack (eating straw, taking straw from the straw rack, rooting the straw rack with the snout)
Others:	
Eating/drinking	Head in trough eating or drinking
Farrowing	
Birth of liveborn piglet	Time of birth of every liveborn piglet
Birth of stillborn piglet	Time of birth of every stillborn piglet (no movement visible)

502

Table 2

Number of posture changes, amount of time per hour sows were active and performing nest building behaviour during the 24 hours before birth of the first piglet in confined and loose housed sows of parity one or parity two to three[1].

	Confined		Loose			P value		
	Parity 1	Parity 2,3	Parity 1	Parity 2,3	SE	Housing	Parity	Housing × Parity
Sows, n	20	21	20	20				
Posture changes, n	372	274	362	260	28.5	0.676	<0.001	0.947
Active, s/h	384 (304-473)	511 (421-610)	566 (469-673)	648 (543-762)	-	0.002	0.033	0.534
Nest building behaviour[2], s/h	302 (228-389)	408 (322-505)	482 (385-589)	550 (447-664)	-	0.001	0.066	0.579
Biting or rooting pen fixtures, s/h	62 (40-89)	89 (63-119)	68 (45-96)	49 (30-73)	-	0.195	0.854	0.076
Rooting or pawing the floor, s/h	184 (125-253)	245 (178-323)	348 (265-442)	411 (320-513)	-	<0.001	0.118	0.835
Straw directed behaviour, s/h	42 (25-65)	56 (36-81)	44 (26-67)	48 (29-72)	-	0.810	0.408	0.653

[1]Data were square root transformed to endure homogeneity of variance so the back-transformed estimates and 95% confidence intervals are presented

[2]Activity performed as nest building behaviour.

Table 3

Beginning, end and duration of the nest building period, in minutes before birth of the first piglet, in confined and loose housed sows of parity one or parity two to three.

	Confined		Loose			P value		
	Parity 1	Parity 2,3	Parity 1	Parity 2,3	SE	Housing	Parity	Housing × Parity
Sows, n	19	21	20	20				
Beginning of nest building, min	950	1023	1023	1002	72	0.721	0.722	0.518
End of nest building, min	363	237	279	144	43	0.043	0.003	0.917
Duration of nest building, min	647	846	804	918	84	0.178	0.067	0.618

Table 4

Number of posture changes, bouts per hour, bout length and total duration in each position per hour during the nest building period in confined and loose housed sows of parity one or parity two to three.

	Confined		Loose			P value		
	Parity 1	Parity 2,3	Parity 1	Parity 2,3	SE	Housing	Parity	Housing × Parity
Sows, n	19	21	20	20				
Posture changes, n	220	201	240	192	26.9	0.832	0.218	0.600
Lying sternally								
Bouts per hour, n	8.2	5.7	6.7	4.8	0.61	0.055	<0.001	0.623
Bout length, s	113 (92-136)	214 (186-244)	116 (95-139)	199 (170-229)	-	0.748	<0.001	0.427
Total duration, s/h	1277	1395	1155	1191	94.6	0.089	0.420	0.665
Lying laterally								
Bouts per hour, n	3.6	1.5	4.2	2.1	0.38	0.110	<0.001	0.922
Bout length, s	249 (168-345)	479 (364-609)	162 (104-232)	228 (155-315)	-	<0.001	0.003	0.169
Total duration, s/h	1297	951	1039	789	129.5	0.109	0.025	0.711
Sitting								
Bouts per hour, n	4.2	4.1	3.3	3.3	0.53	0.126	0.954	0.862
Bout length, s	34 (26-44)	46 (37-56)	45 (36-55)	68 (56-80)	-	0.010	<0.001	0.227
Total duration, s/h	217	262	265	285	56.6	0.535	0.568	0.830
Standing or walking								
Bouts per hour, n	4.6	4.2	4.6	4.3	0.50	0.974	0.492	0.928
Bout length, s	145	230	192	279	-	0.030	<0.001	0.818

	(114-180)	(192-270)	(157-231)	(237-325)				
Total duration, s	1017	1073	1207	1327	113.8	0.055	0.441	0.781

Table 5

Nest building behaviours per hour performed during the nest building period in confined and loose housed sows of parity one or parity two to three.

	Confined		Loose		SE	P value		
	Parity 1	Parity 2,3	Parity 1	Parity 2,3		Housing	Parity	Housing × Parity
Sows, n	19	21	20	20				
Overall nest building behaviour								
Bouts per hour, n	6.4	5.8	5.1	4.1	0.68	0.032	0.248	0.819
Bout length, s	75 (59-92)	126 (107-147)	109 (90-130)	207 (180-236)	-	<0.001	<0.001	0.080
Total duration, s/h	677 (541-828)	696 (564-841)	792 (647-951)	843 (693-1006)	-	0.082	0.647	0.846
Biting or rooting inventory								
Bouts per hour, n	1.6	1.5	1.0	0.8	0.21	0.001	0.559	0.852
Bout length, s	72 (55-92)	107 (88-129)	91 (72-113)	133 (108-161)	--	0.060	<0.001	0.902
Total duration, s/h	122 (78-175)	156 (108-213)	103 (64-151)	86 (51-131)	-	0.060	0.777	0.286
Rooting or pawing the floor								
Bouts per hour, n	3.9	3.6	3.3	2.8	0.43	0.113	0.309	0.807
Bout length, s	70 (53-89)	118 (96-141)	122 (99-147)	220 (188-254)	-	<0.001	<0.001	0.167
Total duration, s/h	370 (275-478)	415 (319-524)	583 (465-714)	624 (502-759)	-	<0.001	0.448	0.899
Straw directed behaviour								
Bouts per hour, n	0.9	0.7	0.8	0.5	0.17	0.531	0.183	0.944
Bout length, s	114	177	89	164	-	0.299	<0.001	0.620

	(82-151)	(139-219)	(62-120)	(123-210)				
Total duration, s/h	110 (59-176)	93 (49-152)	61 (26-110)	65 (28-116)	-	0.117	0.842	0.693

521

Table 6

Farrowing duration, birth interval, number of total born, live born and stillborn piglet in confined and loose housed sows of parity one or parity two to three.

	Confined		Loose		SE	P value		
	Parity 1	Parity 2,3	Parity 1	Parity 2,3		Housing	Parity	Housing × Parity
Sows, n	20	21	20	20				
Farrowing duration, min	199 (154-250)	324 (268-386)	241 (192-297)	328 (269-392)	-	0.373	<0.001	0.434
Birth interval, min	14 (11-17)	18 (15-22)	16 (13-20)	19 (15-22)	-	0.298	0.043	0.536
Total born, n/litter	15.8	19.3	16.1	18.7	0.58	0.7	<0.001	0.450
Live born, n/litter	15.3	18.0	15.6	18.0	0.54	0.853	<0.001	0.785
Stillborn, n/litter	0.5 (0.3-0.9)	1.3 (0.9-1.9)	0.5 (0.3-0.9)	0.7 (0.4-1.2)	-	0.273	0.018	0.273

Figure 1

Salivary cortisol concentrations during the nest building period in confined and loose housed sows of parity one or parity two to three.